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INVESTIGATION OF THE EFFECTS OF RESTRAINT DESIGN VARIATIONS ON HUMAN RESPONSES TO IMPACT

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INTRODUCTION

Design criteria that are available for the development of personnel restraint systems are frequently based upon individual judgment or limited testing with anthropometric dummies or the precedence of existing operational equipment designs. Recent United States Air Force (USAF) accident investigation findings have focused attention upon the fact that the design criteria are, in some cases, not supported by data that are based upon human test results. Increasing cost of equipment changes make it vital that requirements for such changes and the guidance provided for personnel protective equipment design be fully substantiated by adequate data. In view of this situation, the Aerospace Medical Research Laboratory (AMRL) has initiated an experimental research program to investigate the influence of specific, fundamental restraint system design configuration variations on human inertial and kinematic responses to impact acceleration. These variations include the mechanical properties of harness materials, shoulder harness and lap belt attachment geometry, and restraint harness configuration.

This preprint summarizes results of impact experiments that have been conducted to evaluate the influence of the attachment angle of restraint shoulder straps on specific human dynamic responses. Currently accepted design criteria limit this angle to a range of 0 degree to 25 degrees (ref 1). Revisions to the design of the F/FB-111 crew restraint harness have been proposed to reduce the occurrence of vertebral fractures resulting from emergency escape. Shoulder harness angles of less than 0 degree, which are possible within the adjustment range of the F/FB-111 crew seat and restraint system, have been identified as a causative factor in the high spinal injury rate (ref 2). A negative angle will cause vertical compression loads as a reaction to horizontal forces carried by the shoulder straps. Design studies of the F/FB-111 crew seat and restraint have shown that, because of the unique adjustment features of the seat, negative angles cannot be avoided without exceeding the upper limit of the design criteria by approximately 10 degrees. Therefore, human response data for impacts with a 35 degree harness angle were required.

METHODS

Impact tests were accomplished on the AMRL Impulse Accelerator Facility using an anthropometric dummy and volunteer subjects. The test subjects were exposed to $-G_x$ ("eyeballs out") acceleration levels of 6, 8 and 10 G with impact velocities of 6.5, 7.9 and 9.2 m/sec, respectively. The subjects were restrained by a lap belt and shoulder harness constructed of 4.5 cm wide webbing. The seat was designed with conventional USAF crew seat geometry, i.e., a back angle of 13 degrees aft of vertical and a seat pan inclined 6 degrees from the horizontal. The ends of the lap belt and shoulder harness were fastened to triaxial load cells. The harness was tensioned to a level of 89 N ($\pm$22), measured at each of the ends, prior to the test. The seat pan was supported by load cells to measure vertical and horizontal forces during the impact. Two high-speed (500 fps) motion picture cameras were mounted on the impact carriage to record the kinematic responses of the test subjects. The seat and impact carriage acceleration and velocity were measured by instruments attached to the carriage.

Eleven volunteer subjects, nine males and two females, were used in these experiments. The body weight of the subjects ranged from 52.6 to 93.3 kg with a mean of 74.4 kg. The motion of photometric targets attached to specific anatomical sites were measured from the high-speed films to determine body segment trajectories. Three orthogonal accelerometers were mounted against the subjects sternum using a chest harness. A second set was fixed against the teeth using an individually fitted, metal dental casting. The volunteers were prevented from carrying impact loads through their legs by the use of low friction materials between the feet and the floor of the impact carriage.

The anthropometric dummy subject was an Alderson Research Laboratory VIP-95. The joint torques of the dummy were adjusted to the one G values recommended by the National Highway Traffic Safety Administration.

The nominal angle of the lap belt was 46 degrees with respect to the floor of the impact carriage. The centerline of the lap belt was aligned to intercept the seat reference line (a line formed by the intersection of the planes of the seat back and seat pan). The angle of the shoulder harness, between the shoulder strap and a horizontal line at the shoulder, was 0, 25 or 35 degrees.

The experiments were accomplished in two phases. In the first phase, the shoulder harness angle was set at 0 and 25 degrees. The shoulder straps were attached to a single point behind the seat back. In the second phase, the shoulder harness angles were 25 and 35 degrees and the shoulder straps were attached to points 16 cm apart on a horizontal yoke fastened to the load cell behind the seat back.

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RESULTS

Impact experiments conducted with the anthropometric dummy demonstrated clear differences in the maximum vertical compression forces reacted through the seat pan at acceleration levels of 4, 6, 8, and 10 G and at the three shoulder harness angles (α = 0.001). Figure 1 shows plots of the vertical forces measured by the force cells under the seat pan versus shoulder strap angle. The forces have been divided by the dummy's weight to aid comparison with larger or smaller human subjects. The peak resultant accelerations measured on the dummy head varied significantly at all acceleration levels for each shoulder harness angle (α = 0.001). Variation of shoulder harness angle did not cause a significant difference in chest acceleration or shoulder harness load.

Table 1 summarizes the mean values ($\bar{x}$) and estimated standard deviations (σ) for human test data where relevant changes were observed in the dummy test data for shoulder harness angle changes. This table shows that the vertical loads measured at the seat pan reflect the shoulder harness angle change between 0 and 25 degrees but not between 25 and 35 degrees. This difference is statistically significant when the data are analyzed by comparing the means of the two groups of data (α = 0.01) or by pairing the data by individual subjects (α = 0.01). The differences between the mean values of peak head accelerations, peak chest accelerations, and peak shoulder harness load/weight for each set of shoulder harness angles are not significant.

Comparison of human and dummy data sets reveal that the data collected with the dummy cannot be used to reliably predict human responses. Figure 2 shows the differences between the peak resultant acceleration measured on the dummy and human heads at 0 and 35 degree shoulder strap angles. If the dummy test data are used to predict human acceleration peaks, the prediction is incorrect in terms of both degree of change as a function of angle and also in the magnitude at the 6 and 10 G carriage acceleration levels. The dummy test results showed that seat pan loads, the chest accelerations and shoulder harness loads were consistently higher than data from the human tests while the head accelerations were consistently lower.

The tests with volunteer subjects conducted at 25 and 35 degree strap angles have shown no significant difference in any of the measurements or in the subjective responses of the subjects. This finding must be used with caution, however. The higher shoulder harness angle potentially degrades the safety of personnel during sideward (G_y) impact since the shoulder straps bear against the upper portion of the neck.

REFERENCES

1. Crash Survival Design Guide, USAAMRDL Technical Report 71-22, October 1971.

2. Kazarian, L. E., F/FB-111 Escape Injury Mechanism Assessment, AMRL Technical Report 77-60, October 1977.

TABLE 1. Data From 10 G Tests with Human Subjects

	SHOULDER HARNESS ANGLES			
	0°*	25°*	25°**	35°**
Head Acceleration (G)	$\bar{x}$ = 24.5 σ = 5.87	$\bar{x}$ = 23.8 σ = 6.12	$\bar{x}$ = 24.5 σ = 2.90	$\bar{x}$ = 24.1 σ = 4.87
Chest Acceleration (G)	$\bar{x}$ = 17.6 σ = 4.27	$\bar{x}$ = 15.7 σ = 2.05	$\bar{x}$ = 15.8 σ = 2.53	$\bar{x}$ = 14.6 σ = 2.72
Shoulder Harness Load/Weight	$\bar{x}$ = 5.72 σ = 0.88	$\bar{x}$ = 6.01 σ = 0.71	$\bar{x}$ = 5.66 σ = 0.92	$\bar{x}$ = 5.37 σ = 1.13
Vertical Seat Pan Load/Weight	$\bar{x}$ = 8.50 σ = 0.62	$\bar{x}$ = 6.98 σ = 0.79	$\bar{x}$ = 6.78 σ = 0.77	$\bar{x}$ = 6.95 σ = 0.43
	n = 8	n = 10	n = 5	n = 5

*Single point attachment.
**Two point attachment.

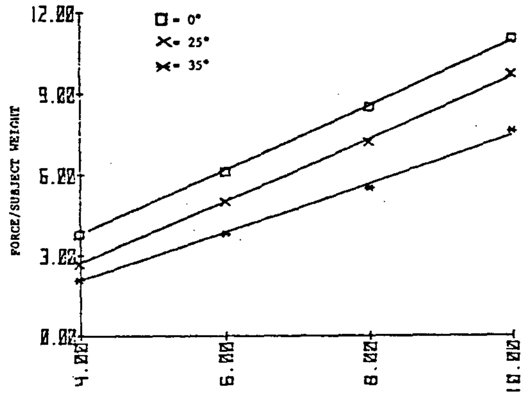

FIGURE 1. MAXIMUM VERTICAL FORCES REACTED THROUGH THE SEAT PAN WITH DUMMY SUBJECT AT 0°, 25° AND 35° SHOULDER STRAP ANGLES.

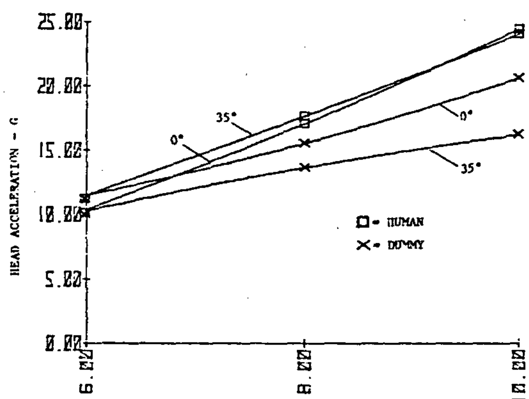

FIGURE 2. MAXIMUM RESULTANT ACCELERATION MEASURED ON THE HUMAN AND DUMMY HEADS AT 0° AND 35° SHOULDER STRAP ANGLES.

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